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# Two Giant Planets Orbiting the K Giant Star $\eta$ Cet

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**Abstract.** We present evidence of a new planetary system around the K giant $\eta$ Cet (HIP 5364, HD 6805, HR 334), based on 124 high-precision optical and infrared radial velocity data, taken at Lick Observatory (Hamilton) and at VLT (CRIRES). The best dynamical fit to the data is consistent with two massive planets ($m_1 \sin i \approx 2.6 M_{Jup}$, $m_2 \sin i \approx 3.3 M_{Jup}$) and with periods of $P_1 \approx 407$ days, $P_2 \approx 740$ days. To test the $\eta$ Cet system's stability we perform $\sim$ 10,000 dynamical investigations with maximum time spans of $10^8$ years. We find that in case of moderate eccentricities, the planets can be effectively trapped in an anti-aligned stable 2:1 mean motion resonance (MMR), very close to the separatrix. A larger non-resonant stable region exists in low-eccentricity parameter space, although less probable than the 2:1 MMR region.

**Keywords.** techniques: radial velocities, methods: numerical, planetary systems

## 1. Introduction

More than 133 known multiple-planet systems are present in the literature up to June 2013; their number is constantly growing. Nevertheless, not many multiple planetary systems have been found around evolved giant stars so far. For more than a decade we have been studying 373 very bright (V $\leqslant$ 6 mag) G and K giants (Frink *et al.* 2001) using high precision Doppler spectroscopy in an attempt to discover planetary companions around intermediate-mass stars. In this study we report the detection of two Jovian planets orbiting the K giant $\eta$ Cet. This system is only the fourth known planetary system around a G and K giant stars and presents an important milestone for understanding planetary formation and evolution as a function of stellar mass, metallicity and age.

## 2. Observations

Between Jul. 2000 and Dec. 2011, 118 optical Doppler measurements for $\eta$ Cet have been obtained with the Hamilton Échelle Spectrograph at Lick Observatory ($R \approx$ 60,000, $\sigma$ = 3-5 ms$^{-1}$). Starting Oct. 2011, six additional near-IR data points have been taken with CRIRES ($R \approx$ 100,000, $\sigma$ = 40 ms$^{-1}$). Assuming the mass of $\eta$ Cet to be $1.7 M_{\odot}$ (Reffert *et al.* submitted) the dynamical model suggests that the $\eta$ Cet system contains two strongly interacting giant planets. The orbital parameters and their estimated errors from the best dynamical fit are summarized in Table 1.

## 3. Dynamical tests

For the stability test we have used the *Mercury* N-body simulator (Chambers 1999). We took input orbital parameters from a grid of best fits for fixed $e_1$ and $e_2$ (Fig. 1 f,g). Each grid pixel is an output orbital parameter set from the orbit fitting routine, with the stellar jitter (r.m.s. = 15.1 ms$^-$1) quadratically added into $\sigma_{RV}$. Using those grids as an input ($\sim$10,000 fits), we find two permitted stability regions for the $\eta$ Cet planetary system: either non-resonant in near-circular orbits, or with higher probability in a moderate $e_2$ regime, where the system appears to be in an anti-aligned 2:1 MMR. In this configuration the lowest order eccentricity-type resonant angle $\theta_1$ librates around 180° and $\theta_2$ librates

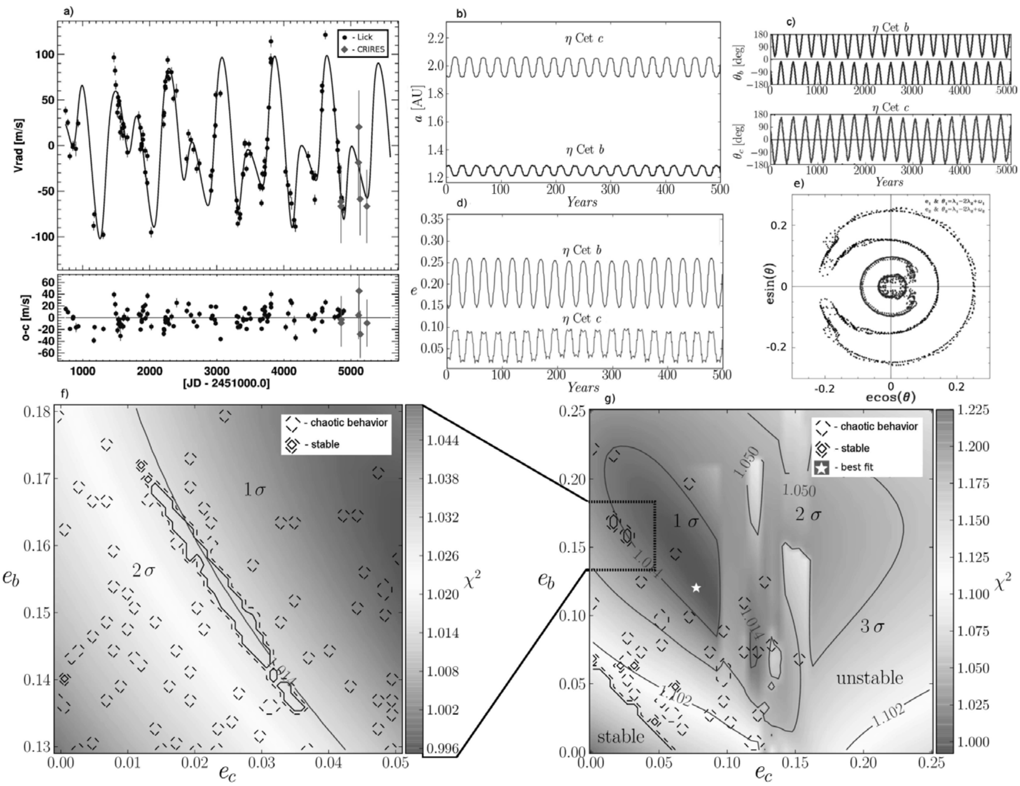


**Figure 1. a)** The best fit model to the data. **b)** Semi-major axis evolution: the planets exhibit strong perturbations, but are bound in stable orbits for at least $10^8$ yr. The mean period ratio is 2:1. **d)** Eccentricities are rapidly changing with the same phase. **c)** The resonance angles $\theta_1$ and $\theta_2$ librate with very large amplitudes of $\sim \pm 180°$ – very close to the separatrix, however **e)** shows that the system is always in an anti-aligned planetary configuration. **g)** Illustrates the two stable regions in the $e_1/e_2$ plane, while **f)** shows the 2:1 MMR region with higher resolution.

**Table 1.** Best fit orbital parameters of the $\eta$ Cet planetary system.

| | $P$ [days] | $m$ sini $[M_{Jup}]$ | $e$ | $\chi^2_{red}$ | $r.m.s.[ms^{-1}]$ |
|---|---|---|---|---|---|
| $\eta$ Cet b | 407.5 ± 2.7 | 2.6 ± 0.2 | 0.12 ± 0.05 | 1.013 | 15.2 |
| $\eta$ Cet c | 739.9 ± 4.9 | 3.3 ± 0.2 | 0.08 ± 0.04 | | |

around 0° with very large amplitudes of $\sim \pm 180°$ (Fig. 1 c,e). In fact as $\theta_1$ and $\theta_2$ are almost circulating, the system is very close to the separatrix.

## 4. Conclusions

We provide evidence that the $\eta$ Cet system contains two strongly interacting giant planets. The dynamical simulations show that it is very likely that the system is trapped in an anti-aligned 2:1 MMR, although a non-resonant system with near circular orbits is also possible. The $\theta_1 \approx 180°$ and $\theta_2 \approx 0°$ 2:1 MMR configuration is unusual, because it has not been seen so far in smooth migration capture (e.g., Lee 2004).

## References

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